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JSAMS-1717; No. of Pages 5
ARTICLE IN PRESS
Journal of Science and Medicine in Sport xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Journal of Science and Medicine in Sport
journal homepage: www.elsevier.com/locate/jsams

Original research

The influence of cadence and shoes on patellofemoral joint kinetics in runners with patellofemoral pain

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ARTICLE INFO

Article history:
Received 27 February 2017
Received in revised form 7 July 2017
Accepted 26 September 2017
Available online xxx

Keywords:
Knee pain
Footwear
Gait
Running
Biomechanics

ABSTRACT

Objectives: To determine the effect of a combination of a minimalist shoe and increased cadence on measures of patellofemoral joint loading during running in individuals with patellofemoral pain.
Design: Within-participant repeated measures with four conditions presented in random order: (1) control shoe at preferred cadence; (2) control shoe with +10% cadence; (3) minimalist shoe at preferred cadence; (4) minimalist shoe with +10% cadence.
Methods: Fifteen recreational runners with patellofemoral pain ran on an instrumented treadmill while three-dimensional motion capture data were acquired. Peak patellofemoral joint stress, joint reaction force, knee extensor moment and knee joint angle during the stance phase of running were calculated. One-way repeated measures ANOVA was used to compare the control condition (1) to the three experimental conditions (2–4).
Results: Running in a minimalist shoe at an increased cadence reduced patellofemoral stress and joint reaction force on average by approximately 29% ($p < 0.001$) compared to the control condition. Running in a minimalist shoe at preferred cadence reduced patellofemoral joint stress by 15% and joint reaction force by 17% ($p < 0.001$), compared to the control condition. Running in control shoes at an increased cadence reduced patellofemoral joint stress and joint reaction force by 16% and 19% ($p < 0.001$), respectively, compared to the control condition.
Conclusions: In individuals with patellofemoral pain, running in a minimalist shoe at an increased cadence had the greatest reduction in patellofemoral joint loading compared to a control shoe at preferred cadence. This may be an effective intervention to modulate biomechanical factors related to patellofemoral pain.

1. Introduction

Patellofemoral pain (PFP) is the most common musculoskeletal complaint in runners.[1] PFP is defined as pain around or behind the patella that is aggravated by weight bearing activities that load the patellofemoral joint (PFJ).[2] Although the aetiology of PFP is not well understood, there is evidence to implicate the role of excessive PFJ stress in the pathophysiology of PFP.[3–5] Repetitive high-frequency loading of the PFJ may exacerbate PFJ symptoms due to an elevated patellar water content[6] or subchondral bone metabolic activity.[7] This suggests that it is worthwhile to evaluate strategies that reduce PFJ stress in those with PFP.

In healthy individuals, evidence suggests that traditional cushioned footwear can elevate PFJ stress[8] while an increased running cadence can reduce PFJ load.[9] Running in traditional cushioned footwear can elevate PFJ stress via kinematics changes such as a longer stride length and greater knee flexion during stance that create a larger moment arm of the quadriceps muscles.[8] An effective strategy to reduce stride length and knee flexion during stance is to increase running cadence.[9,10] A 10% increase in running cadence has also been shown to reduce PFJ reaction force in healthy individuals.[9,10] These findings suggest that utilising a less cushioned shoe or running with a higher cadence may be effective strategies to reduce PFJ loading in runners. Combining both

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https://doi.org/10.1016/j.jsams.2017.09.593
1440-2440/

Table 1
Demographic and clinical characteristics of participants, described as mean (SD) or *n* (%) unless otherwise stated.

Characteristics	n = 15
Age (years)	32.6 (9.6)
Sex (F:M)	12:3
Height (m)	1.71 (0.06)
Body mass (kg)	68.91 (10.99)
Body mass index (kg m^{-2})	23.30 (3.07)
Anterior knee pain scale[a]	79.67 (6.99)
Worst pain[b]	45.7 (17.3)
Duration of symptoms (months)	49.87 (48.38) Range (2–156)
Number with bilateral knee pain	5 (33%)
Running volume (km/wk)	15.60 (7.4) Range (10–32)

[a] Anterior knee pain scale ranges from 0 to 100 points, where higher scores indicate less disability.
[b] Pain measured on 100 mm visual analogue scale; 0 mm = no pain, 100 mm = worst pain imaginable.

the minimalist shoe and reduced step length may yield a greater reduction in knee joint load during running as compared to either minimalist footwear or reduced step length in isolation.[11]

Although data from healthy individuals support the use of minimalist footwear and gait modification to reduce PFJ load, these observations cannot be generalised to individuals with PFP. Individuals with PFP present with altered running biomechanics compared to healthy controls.[12] Those with PFP have also demonstrated dissimilar changes in PFJ stress compared to healthy controls when altering step length during running.[13] Taken together, an evaluation of the combined effect of minimalist shoes and gait modification on PFJ stress in individuals with PFP is needed.

Given that higher PFJ stress is considered to adversely affect PFP patients,[3] the primary aim of this study was to examine the effect of a minimalist shoe and increased running cadence on PFJ stress in individuals with PFP. We hypothesised that the combination of a minimalist shoes and increased cadence would have the greatest reduction in PFJ stress compared to control shoes and preferred cadence. Secondary aims of this study were to evaluate the effect of running in (1) a control shoe and increased cadence; (2) a minimalist shoe with preferred cadence; (3) a minimalist shoe and increased running cadence on PFJ reaction forces, knee extensor moment and knee flexion angle compared to a control shoe and preferred cadence.

2. Methods

Fifteen recreational runners people who had clinically diagnosed PFP participated in this study. Descriptive characteristics are presented in Table 1. Participants were predominately female, had moderate level of anterior knee pain and ran on average approximately 16 km per week. The diagnosis of PFP was made based upon previous clinical trials,[14,15] whereby participants were initially telephone-screened prior to a physical examination. The inclusion criteria were: (i) aged 18–40 years; (ii) running at least 10 km per week; (iii) non-traumatic retropatellar pain of greater than 6 weeks duration; (iv) aggravated by at least two of: running, hopping, squatting, prolonged sitting or kneeling; (v) pain severity ≥30/100 mm on a visual analogue scale; and (vi) pain on palpation of the patellar facet or during a double leg squat or step down from a 25 cm step. Exclusion criteria were: (i) concomitant injury or pathology of other knee structures (e.g. menisci, ligamentous, patellar tendon, iliotibial band); (ii) a history of lower limb surgery; (iii) pain or injury in the hip, pelvis or lumbar spine; and (iv) any foot condition that precluded use of a minimalist shoe. All participants self-reported a history of running in standard cushioned shoes. Written informed consent was obtained from all participants and ethical approval was granted by the Deakin University Human Ethics Committee.

Participants performed 5 min of running on an instrumented treadmill (Bertec, Ohio, USA) in four randomly ordered conditions: (1) control shoe at preferred cadence; (2) control shoe at +10% preferred cadence; (3) minimalist shoe at preferred cadence; and (4) minimalist shoe at +10% preferred cadence. Preferred cadence (steps/min) and foot-strike pattern was determined from sagittal plane video footage (Casio Exilim, Casio, Japan) during the final minute of a 4 min treadmill run in each shoe prior to data collection. A metronome (Seiko DM51, Seiko Instruments Inc, Japan) was used to control cadence during +10% conditions, and trials were only accepted if participants achieved the desired cadence. The control shoe was an Asics Gel-Cumulus 16, with a weight of 345 g, stack height of 31 mm and a 11 mm heel–toe offset. The minimalist shoe was a Vibram Seeya, with a weight of 136 g, stack height of 5 mm and a 0 mm heel–toe offset. A 5 min rest period was provided between conditions for recovery and to change shoes if required.

An eight-camera VICON motion analysis system (Oxford Metrics Ltd, Oxford, UK), sampling at 250 Hz was used to capture three-dimensional joint kinematics of the lower limb. Ground reaction force (GRF) data were collected at 1500 Hz from the instrumented treadmill in synchrony with the motion capture data. Thirty-two 14 mm retroflective markers were attached to anatomical landmarks in accordance with an established model.[16] Markers were placed bilaterally on the iliac crest, anterior and posterior iliac spines, greater trochanter, anterior and lateral thigh and shank, medial and lateral epicondyles of the femur, medial and lateral malleolus, calcaneus and the base of the third and fifth metatarsals. Kinematic and GRF data were processed within Visual 3D software (C-Motion, Rockville, Maryland, USA). Marker trajectories and GRF data were low pass filtered with a 20 Hz cut-off frequency. The cut-off frequency was determined via a residual analysis and visual inspection of the resulting kinematic and GRF data. The net internal knee extension moment was obtained by submitting filtered kinematic and GRF to a conventional Newton-Euler inverse dynamics analysis. Joint moment data was normalised by body mass and reported in units of Nm/kg. Gait events were identified by the use of a 60 N threshold of the vertical GRF. Data were extracted for the affected limb for 20 strides during the final minute of the 5 min run in each condition using a customised MATLAB (Mathworks Inc, Natick, USA) programme. In the case of bilateral symptoms, the most symptomatic leg was used for analysis.

Kinetic data related to the PFJ were derived from kinematic and kinetic data using a previously described biomechanical model.[17–19] This model has been used to estimate PFJ reaction force (PFJRF) and stress during walking,[18] running,[8,20] and squatting[21] and is sensitive to detect changes in PFJ stress with different footwear[22] and knee braces.[23] Quadriceps force was calculated for each knee flexion angle by dividing the net knee extensor moment by the effective lever arm for the quadriceps. The quadriceps effective lever arm was determined at each knee flexion angle by fitting a non-linear equation to the data of van Eijden et al.[24] The PFJRF was estimated by multiplying the quadriceps force by a constant[25] that defines the relationship between PFJRF and knee flexion angle. PFJ stress was estimated by dividing the PFJRF by PFJ contact area. PFJ contact area was estimated by fitting a fourth order polynomial curve to the contact areas for each knee flexion angle as reported previously.[26] The output of the model was PFJRF and PFJ stress as a function of knee flexion angle during the stance phase of the gait cycle.

The data for each participant were averaged over the 20 strides for each condition and normalised to the stance phase of the gait cycle. Variables of interest included: (1) peak PFJ stress; (2) peak PFJRF; (3) peak knee extensor moment and (4) peak knee flexion angle, which served as the dependent variables. The independent